PB85-180842

Demonstration Test of Refuse-Derived Fuel as a Supplemental Fuel in Cement Kilns

Maryland Dept. of Natural Resources, Annapolis

Prepared for

Environmental Protection Agency, Cincinnati, OH

Apr 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-180842

EPA/600/2-85/032
April 1985

DEMONSTRATION TEST OF REFUSE-DERIVED FUEL AS A SUPPLEMENTAL FUEL IN CEMENT KILNS

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Grant No. R-805-613

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/2-85/032		PB85 180842/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Demonstration Test of Refuse-Derived Fuel as a Supplemental Fuel in Cement Kilns	April 1985
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Cliff Willey & Carl Weinberger	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Maryland Department of Natural Resources Annapolis, Maryland 21401 and Teledyne National Cockeysville, Maryland 21030	11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Hazardous Waste Engineering Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	14. SPONSORING AGENCY CODE EPA 600/12

15. SUPPLEMENTARY NOTES

Project Officers: Michael I. Black and Robert Olexsey

16. ABSTRACT

Fluff refuse-derived fuel (RDF) from Baltimore County, Maryland, residential solid waste was successfully tested as a supplementary fuel with pulverized coal in a large rotary cement kiln. RDF was produced at the Baltimore County Resource Recovery Facility, a joint project of Baltimore County and the State's Maryland Environmental Service. Tests were conducted by Teledyne National in cooperation with the Lehigh Portland Cement Company.

A total of 1400 tons of RDF was burned in a 700 ton-per-day kiln, contributing an average of 30 percent of the kiln heat. There were four days of initial testing followed by a 27-day extended test of which 20 days involved burning RDF. Cement quality and chemistry, RDF characteristics and air emissions were determined.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	Unclassified	75
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes research done at Baltimore County, Maryland, where refuse-derived fuel from residential solid waste was successfully tested as a supplementary fuel with pulverized coal in a large rotary cement kiln.

For further information, please contact the Alternative Technologies Division, of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

PREFACE

In 1973, Baltimore County, Maryland, and the Maryland Environmental Service (MES), the State's waste management utility, agreed to a joint venture that would provide, first of all, a reliable municipal solid waste shredding/transfer facility for the county and, secondly, a facility to develop and demonstrate the technology of dry materials recovery as a means to reduce the County's dependence on landfill for waste disposal. Teledyne National was selected to design, manage construction, and operate the facility.

Groundbreaking for the facility occurred in August 1974 and the shred/transfer operation was initiated in the spring of 1976.

It was recognized in the establishment of this program that both markets and technology needed development. As a result, a "market development program" was initiated to run concurrent with the construction and development of the resource recovery plant. Teledyne National was responsible for this program also.

In early 1975, market development work was begun and discussions were held with more than 30 industrial firms, institutions, and State organizations regarding their interest in burning refuse-derived fuel (RDF). As a result of this effort, discussions were begun with the Lehigh Portland Cement Company and a test program for RDF was developed.

During 1976 and 1977, preliminary work was done under the Baltimore County/MES Market Development Program, and Grant No. S-804786 from the U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. On September 26, 1978, the grant for which this report was prepared, Grant No.

R-805-613, "Refuse-Derived Fuel as a Supplementary Fuel in Cement Kilns" was awarded by the U.S. Environmental Protection Agency to the State of Maryland (Maryland Environmental Service) to complete the test program. This grant provided for 30 days of test burning refuse-derived fuel. Tests under the grant were conducted by Teledyne National and the Lehigh Portland Cement Company.

Mr. Carl Weinberger was Chief Project Engineer for Teledyne National. Dr. Cliff R. Willey, Chief of Technical Services, Maryland Environmental Service, served as a Project Manager for the grant. Due to a change of employment by Mr. Weinberger, this report was prepared by Dr. Willey, based on data, interim reports, and a draft final report prepared by Mr. Weinberger, and information provided by Teledyne National and the Lehigh Portland Cement Company, and other reference sources.

ABSTRACT

Fluff refuse-derived fuel (RDF) from Baltimore County, Maryland, residential solid waste was successfully tested as a supplementary fuel with pulverized coal in a large rotary cement kiln. RDF was produced at the Baltimore County Resource Recovery Facility, a joint project of Baltimore County and the State's Maryland Environmental Service. Tests were conducted by Teledyne National in cooperation with the Lehigh Portland Cement Company.

A total of 1400 tons of RDF was burned in a 700 ton-per-day kiln, contributing an average of 30 percent of the kiln heat. There were four days of initial testing followed by a 27-day extended test of which 20 days involved burning RDF. Cement quality and chemistry, RDF characteristics and air emissions were determined.

Satisfactory Type I and Type II cements were produced. In initial tests, at 37 percent RDF heat, a Type I cement with strengths of 4,000 (3-day), 4,870 (7-day), and 5,800 psi (28-day), compared to ASTM minimum standards of 1,800, 2,800 and 4,000 psi, was produced. Satisfactory strengths also occurred in succeeding tests for a Type II cement. Chemical analysis by the Portland Cement Association showed little difference between clinker produced with RDF supplemental fuel and normal production cement.

Finely shredded RDF was required to achieve satisfactory burning in suspension in the kiln; the RDF size required for the tests was roughly 95 percent less than 2.5 cm (1 in.). Average values for all tests (106 samples) on RDF were: heating value - 6495 Btu per pound, moisture content - 20.1 percent, and ash - 11.5 percent. Sulfur content was about 0.2 percent.

Air emission tests consisted of three sampling runs with coal cnly and three with coal and RDF. Sampling was done at the stack following gas clean-up by electrostatic precipitators. Analysis was done for particulates (EPA method 5), SO_x (method 6), chlorides (as HCL) and NO_x. A precipitator malfunction and clean-out occurred just prior to the tests.

Particulates averaged 0.022 gr/dscf while burning coal and 0.059 gr/dscf while burning coal and RDF. SO_x results appeared to be affected by the precipitator clean-out. Chlorides increased slightly; NO_x was not significantly affected. Dust buildup in the ESP's was noted when burning RDF, indicating that some adjustment to the precipitators may be needed when using RDF, to achieve maximum particulate clean-up of the gas stream.

The report also discusses RDF preparation equipment and RDF feed equipment developed for the tests.

This report, submitted in fulfillment of Grant No. R-805-613 by the Maryland Environmental Service under the sponsorship of the U.S. Environmental Protection Agency, covers the period September 26, 1977 to June 30, 1980. Work was completed by August 1, 1980.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

MES	- Maryland Environmental Service
PCA	- Portland Cement Association
LPC	- Lehigh Portland Cement Company
MSW	- Municipal Solid Waste
BCRRF	- Baltimore County Resource Recovery Facility
NCRR	- National Center for Resource Recovery
RDF	- Refuse-Derived Fuel
LWA	- Lightweight Aggregate

ACKNOWLEDGMENTS

The cooperation of the Lehigh Portland Cement Company is gratefully acknowledged. We are particularly grateful for the assistance provided by Mr. Robert C. Durdock - Operations Manager, Mr. David H. Roush - Assistant Operations Manager, and Mr. L. Harvey Kirk - Kiln Engineer.

The cooperation of Mr. Charles Farley, Director, Bureau of Sanitation, and Mr. Gene Neff, Deputy Director of Public Works, Baltimore County, Maryland, also is gratefully acknowledged.

In addition to the grant from the U.S. Environmental Protection Agency, contributions were made to this project by Teledyne National, Lehigh Portland Cement Company and the Portland Cement Association.

SECTION 1

INTRODUCTION

The cement manufacturing industry represents an attractive opportunity to recover energy from municipal solid waste. The industry consumes significant amounts of energy, 457 trillion Btu per year (1), and includes 49 plants with capacities to use over 380 tons per day of refuse-derived fuel (2). The State of Maryland owns one of these plants. The use of refuse-derived fuel (RDF) involves a process in which ash and other products of combustion become part of the manufactured product, thus minimizing the requirement for ash disposal and reducing the need for costly additional air pollution control equipment.

In spite of this attractiveness, progress towards the use of RDF in the cement industry has been slow, tempered by industry caution on one hand and a lack of test information on the other. None of the tests in the United States has involved more than five test days (2).

In 1975, when discussions were begun with the Lehigh Portland Cement Company regarding potential use of refuse-derived fuel in the production of cement, it became apparent that, even though there was interest, there also were concerns about the untried nature of the fuel. These concerns included uncertainties regarding:

- ability to supply and feed RDF continuously
- firing characteristics and ability to burn RDF in suspension
- effect of RDF chemical composition and variations in composition on cement quality and chemistry

o long-term effects of RDF on kiln operation and cement production
o effect on air emissions

It also became apparent that extensive testing would be required to develop this RDF market.

As additional discussions were held with Lehigh, the following test program was developed to address their concerns:

(1) It was agreed that RDF would first be tested at a coal-fired, lightweight shale kiln. The advantage of this test would be that experience could be gained with the burning characteristics of RDF and the reliability of RDF feed equipment without facing concerns about cement quality and production. As part of the test, it was also agreed that the feed equipment would provide seven days of continuous operation before permission would be given to begin tests at the cement plant.

(2) Provided there was satisfaction with the lightweight aggregate test, RDF feed equipment would be set up at a cement plant to produce test quantities of cement for analysis (2- to 3-day test).

(3) Again based on satisfaction with the previous step, an extended burn test involving air emission measurements would be run.

Tests subsequently were conducted at a Lehigh-owned, lightweight aggregate (LWA) plant at Woodsboro, Maryland and a cement plant at Union Bridge, Maryland. A location map is presented in Figure 1 showing locations of these plants and the Baltimore County Resource Recovery Facility (BCRRF) which was the source of RDF for the tests.

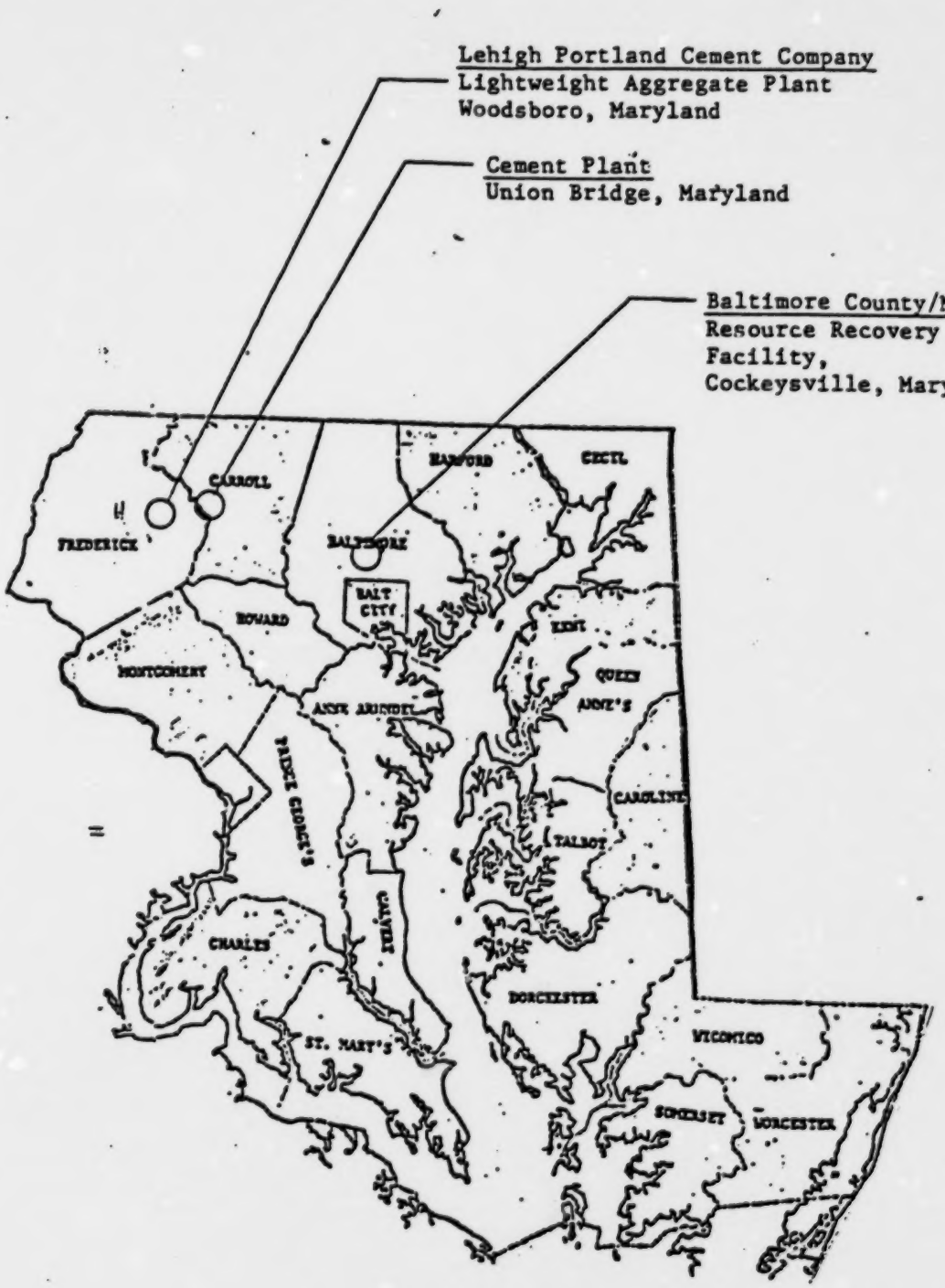

FIGURE 1. LOCATION MAP

SECTION 2

CONCLUSIONS

o Satisfactory Type I and Type II cement were produced burning coal supplemented with refuse-derived fuel. Physical properties, such as strength and set time, were within acceptable limits. Chemical composition of cement produced with RDF and coal was not significantly different from cement produced with coal alone. No alteration of the infeed raw material mix was needed to adjust for differences in chemical makeup caused by substitution of RDF for coal. These results apply to the test conditions in which up to 37 percent of the heat was supplied by RDF.

o Fluff RDF (as well as the primary fuel) must burn in suspension to avoid causing low oxygen (reducing) condition at the kiln bed and subsequent unacceptable changes in cement chemistry. It was concluded that for the conditions of this test that RDF required secondary shredding to a size 95 percent less than 2.5 cm (1 in.) for suspension burning. Coarser or finer shredded RDF may be required for different kiln conditions, feed techniques, and feed rates. Nozzle size also had to be reduced.

o Although stack emission tests were probably affected by a precipitator outage and cleaning prior to the test period and must be interpreted with caution, none of the emissions tested--particulates, chlorides, nitrous oxides, and sulfur oxides--appeared to present a serious problem. Ash buildup in the ESP with time, after starting to burn RDF, indicated RDF may have affected the properties of the dust-fly ash mix collected by the ESP's and that some adjustment in operating conditions might be required if RDF were burned on a continuous basis.

o Fluff RDF can be stored in transfer trailers and reliably fed from the trailers provided that: (a) the RDF is only moderately compacted in the trailers, (b) lump breakers or some other means is used to refluff and even out the flow of RDF, and (c) the rate of trailer unloading and the speed of the feed conveyors are adjustable.

SECTION 3

RECOMMENDATIONS

Long term tests of RDF as a cement kiln fuel should be continued to establish industry confidence in the use of this fuel. The best approach may be the development of a semi-automated feed station for continuous RDF fuel use at a cement manufacturing plant.

SECTION 4

BACKGROUND AND OVERVIEW OF TEST PROGRAM

CEMENT MANUFACTURING AND USE OF RDF

Cement manufacturing is an energy intensive industry. The 1978 energy report for the U.S. Portland Cement industry showed the U.S. cement industry used 6.13 million Btu of energy per ton of cement clinker production. The same report gave the 1978 production capacity as 74,550,000 tons and total energy use as 457 trillion Btu (1).

There has been a rapid conversion in the cement industry from other fuels to coal since 1973. In 1973, just over a third of the industry's capacity used coal; by 1979, 77% used coal (3).

Cement manufacturing typically consists of the following steps:

(1) grinding and mixing raw materials in wet or dry form (limestone, shale and/or clay, silicon oxide and iron-bearing materials)
(2) drying (primarily for the wet process)
(3) calcining (to burn off carbon dioxide from limestone)
(4) clinkering (or burning), a process that takes place at 1,300 to 1,500°C (2,400 to 2,800°F)
(5) cooling, clinker grindings, and addition of gypsum to retard setting time

(See Section 5, Cement Kiln, for additional information on the cement manufacturing process.)

Although some new cement plants use a more energy-efficient, preheated, dry-process system in which only step 4, clinkering, is carried out in the rotary kiln, 80 percent of existing plants still perform steps 2 through 4 in the rotary kiln (1).

According to the Encyclopedia of Chemistry (3), Joseph Aspdin, in 1824, was granted a patent for a product he called Portland cement, which was a mixture of slaked lime and clay, calcined at a higher temperature than had been normally used in producing cement. The product resembled a building stone quarried on the Isles of Portland. More than 50 years after Aspdin received his patent, scientists began to understand the fundamental chemistry of the material he produced. It was found that various crystalline phases were responsible for the properties of Portland cement with alite, tricalcium silicate, being one of the most prominent crystals. Also important in cement is belite, dicalcium silicate, felite, and other crystalline structures. In addition, various oxides, such as magnesium oxide, play an important part in the chemistry of cement.

The two calcium silicate phases usually comprise 75 to 80 percent of the cement and a calcium aluminoferite phase with tricalcium aluminate comprises another 15 to 20 percent of the Portland cement clinker.

The principal materials used in the production of cement are limestone byproducts containing calcium carbonate, or lime from various sources, such as marine shells, marble or chalk, and other materials such as clay, shale or slate. This is combined with a small amount of ferrous material in the form of mill scale or some other form of ferric oxide. The basic chemical elements are calcium, silicon, aluminum and iron.

The composition of raw materials in the production of cement must be carefully monitored and controlled. Small variations in the composition of the raw materials can interfere with the formation of desired phases in the cement clinker. It can also affect the temperatures required to produce clinker and the necessary quality of finished cement (4).

The potential for using RDF as a cement kiln fuel and some of the problems that this may entail have been examined in detail by Duckett and Weiss (4) in a report by the National Center for Resource Recovery (NCRR) for the U.S. Department of Energy. In this excellent report, they review the cement-making process, properties of cement, major research issues, tests that have been performed using RDF in cement kilns, and estimate the overall potential for using RDF in the cement manufacturing industry. This report also looks at the potential for using lime and expanded shale kilns as well.

The research issues identified by Duckett and Weiss (which were similar to the concerns of the Lehigh Portland Cement Company) included (a) handling properties of the fuel, (b) ability to control temperature in the kiln, (c) effect of RDF combustion products on kiln coatings, (d) effect of RDF combustion products on clinker chemistry, (e) changes in physical properties of clinker and cement, and (f) effect on air emissions.

They note that RDF is typically higher in ash and chlorine content but lower in sulfur than most coals, but that the basic elemental composition of RDF is similar to reported compositions for coal. Table 1 compares the chemical composition of ash from the Baltimore County Resource Recovery Facility RDF to some eastern coal ash.

The alkali content of cement is important in some areas of the country because of the potential for "alkali-aggregate" reactions which create an alkali-silicate gel and expansion and cracking of concrete. Duckett and Weiss predict that RDF will cause a slight increase in alkali content with RDF being burned at rates of 30 - 40% of the energy input to the kiln. However, alkali-aggregate reactions are generally not a problem in the mid-Atlantic states so that any increase in alkali content due to burning RDF should not present a problem for the Lehigh Portland Cement Company.

Chlorides are also of concern in some cements because of the potential for corrosion of steel reinforcing bars. It is noted that the chlorine content should not exceed 2%.

TABLE 1. CHEMICAL COMPOSITION OF RDF AND COAL ASH

Analysis	Low Volatile Bituminous Ash a/	High Volatile Bituminous Ash b/	High Volatile Bituminous Ash c/	Refuse-Derived Fuel Ash d/
Ash, dry basis, %	12.3	14.10	10.87	-
Sulfur, dry basis, %	0.7	3.30	3.53	1.38 e/
Analysis of ash, % by wt.				
SiO_2	60.0	47.27	37.64	52.72
Al_2O_2	30.0	22.96	20.11	11.74
TlO_2	1.6	1.00	0.81	-
Fe_2O_2	4.0	22.81	29.28	4.09
CaO	0.6	1.30	4.25	11.77
MgO	0.6	0.85	1.25	2.32
Na_2O	0.5	0.28	0.80	6.17
K_2O	1.5	1.97	1.60	1.65
TOTAL	98.8	98.44	95.74	-

a/ Steam, Its Generation and Use, Babcock and Wilcox, Pocahontas No. 3 Seam, West Virginia.

b/ Ibid. Seam No. 9, Ohio.

c/ Ibid. Pittsburgh Seam, West Virginia.

d/ Baltimore County, Md., Analysis by Penniman and Brown, May 31, 1979, No. 79-48968-2.

e/ This is an analysis of RDF ash after combustion - 1.38 percent sulfur as SO_3. Unburned RDF has a sulfur content of about 0.2 percent as received.

The Duckett and Weiss report also summarizes trials that have been conducted over the past five years using RDF in portland cement plants. Seven portland cement companies have conducted tests, not including the tests described in this report. Four of the tests lasted one week or less. The only tests with some notability are those of the Blue Circle Group in the United Kingdom, which began in 1974, and, in this country, the Gulf Coast Portland Cement Company tests which were conducted by Browning Ferris Industries under a contract with the U.S. Department of Energy. In the latter tests, RDF was co-fired with natural gas. The Blue Circle Group is reported to be routinely using refuse-derived fuel in the production of cement.

In the Gulf Coast tests, which were conducted in 1975 and 1977, a primary shredded RDF (3 to 4 inches nominally in size) was used to produce 20, 30, and 40 percent of the kiln heat. It is reported that, at 20 and 30 percent levels, satisfactory cement was produced, and there were no significant differences between RDF cement and regular cement. At 40 percent, a problem of underburning was encountered. Also, there was difficulty in maintaining temperatures, but equipment problems which occurred at the same time as the test made it difficult to determine whether this was due to the use of RDF. (The large particle size of the RDF, however, undoubtedly made burning in suspension more difficult at the higher input rates.) In these tests, the levels of controlled particulate emissions increased by 25, 20, and 50 percent, respectively, when burning at 20, 30, and 40 percent RDF as compared with emissions during fire of natural gas alone. These emissions, however, were still within Federal standards.

The Portland Cement Association's annual plant information summary (December 31, 1979) (2) lists 149 cement clinker plants in the U.S., operating 342 kilns. Those reported account for over 99 percent of the U.S. production capacity. Clinker production capacity is given as 89 million tons per year. Over 50 percent of the production capacity is in Texas, California, Pennsylvania, Michigan, New York, Missouri, and Florida.

In clinker production capacity, Maryland ranks 17th with three plants:

Lehigh Portland Cement, Union Bridge, Maryland - .883 million tons per year

Marquette, Hagerstown, Maryland - 0.472 million tons per year

Alpha Portland Industries, Lime Kiln, Maryland - 0.413 million tons per year

The clinker capacity numbers for the three plants assumes 310 operating days per year. If we assume that RDF at 6000 Btu/lb could supply 30 percent of the heat to the plants and that the average value of 6.13 million Btu per ton of clinker applies to these plants, the size of the Maryland RDF market would be:

Lehigh	135,000 TPY	435 TPD
Marquette	72,000 TPY	232 TPD
Alpha	63,000 TPY	204 TPD

Where TPY is tons per year, TPD is tons per day, and 310 operating days per year is assumed.

BACKGROUND ON TEST PROGRAM

The Maryland Environmental Service (MES) was the grant recipient and administrative organization for the test program. Teledyne National conducted the tests in cooperation with the Lehigh Portland Cement Company.

The MES is an agency of the Department of Natural Resources of the State of Maryland and a nonprofit, utility-like organization with a full range of authority to plan, develop, finance, construct and operate waste management/ waste treatment facilities. MES was created in 1970 by the Maryland General Assembly for the purpose of improving the land and water environment of the State through the development and implementation of improved waste management techniques. For solid waste, resource recovery technology has been emphasized.

In 1974, MES entered into a contract with Baltimore County to provide a solid waste management system and services. The State and Baltimore County agreed to jointly fund the Baltimore County Resource Recovery Facility (BCRRF) at Cockeysville, Maryland. Teledyne National was selected to design, manage construction of, and operate the facility.

The purpose of the facility was to provide a reliable operation to shred wastes and provide transfer to the County's new remote landfill, while at the same time allowing the development of resource recovery technology that would reduce the County's dependence on landfill.

Groundbreaking for the facility occurred in August 1974 and the shred/transfer operation was initiated in the spring of 1976.

It was recognized in the establishment of this program that both markets and technology needed development. As a result, a $600,000 market development program was initiated to run current with the construction and development of the resource recovery plant. Teledyne National was responsible for this program also.

In early 1975, market development work was begun and discussions were held with more than 30 industrial firms, institutions and State organizations regarding their interest in burning RDF. As a result of this survey, letters of interest were received from a number of potential users, three of whom were cement companies. Of the three cement companies, attention was directed to the Lehigh Portland Cement Company (now a division of Heidelburg Cement, Inc.) because of their interest in a test program and nearness to the BCRRF.

In addition to contacting potential users of RDF, work also was begun under the Market Development Program on a semi-portable RDF feed station that would allow the test burning of refuse-derived fuel at a variety of locations. This equipment was first put to use in 1976 at the P.H. Glatfelter Company, located in Spring Grove, Pennsylvania, a

company which produces paper from wood chips. At this plant, RDF was burned in a boiler designed to burn bark, sawdust, or pulverized coal.

In April of 1976, the Maryland Environmental Service received a grant in the amount of $50,000 from EPA (Grant S-804786) to assist in the development of markets for refuse-derived fuel. Under this grant, work was done in 1976 and 1977 to develop a test program for refuse-derived fuel at the Lehigh Portland Cement Company. This project involved:

(1) Preparation sessions with the cement industry to exchange information, plan RDF burn tests, and resolve initial problems.
(2) Design and modify equipment for receiving, secondary shredding, and pneumatically feeding RDF into a kiln.
(3) Conduct initial tests of equipment to burn RDF in a kiln.
(4) Develop and establish a basis for long-term cement kiln tests with refuse-derived fuel.

Under the EPA grant, and with continuing funding from the Market Development Program, initial work was conducted on the development of test equipment and procedures for test burning refuse-derived fuel in a cement kiln. Much of this work was conducted at a lightweight aggregate kiln owned and operated by the Lehigh Portland Cement Company. Equipment tests were run at this kiln in 1977 as detailed in Appendix A.

In March of 1977, a proposal was submitted to EPA outlining a larger test program that would fulfill a need for longer term testing of refuse-derived fuel and provide environmental testing. A request to submit an application for a grant was received by the Maryland Environmental Service in July of 1977. The award of a grant was made (Grant No. R-805-613). In March of 1978, expansion of the program to include additional work on refuse-derived-fuel production was discussed with EPA. In July of 1978 the grant was amended to include additional equipment tests.

OVERVIEW OF TESTS

Market development work under the above-discussed programs established conditions for the test burning of RDF at the Lehigh Portland Cement Company. As outlined in the Introduction, these conditions included:

(1) A demonstration of feed equipment reliability and RDF burning characteristics in a kiln.

(2) Initial production of test quantities of cement for detailed cement analysis.

These steps had to be accomplished before the desired longer test of RDF at the cement kiln could be accomplished.

As a result, the test program was conducted in three phases as outlined below.

Phase 1 - Equipment Development and Demonstration

In this phase, equipment was modified and tested as needed to provide a system that would produce and feed RDF in such a way as to allow RDF to be burned in a way acceptable to the Lehigh Portland Cement Company. This work included:

(1) Modifications of RDF feeding equipment and secondary shredding equipment to increase system reliability and production.

(2) A demonstration of equipment reliability to the Lehigh Portland Cement Company.

This work was conducted in 1978. In October 1978 a successful one-week test was completed at the Lehigh Portland Cement Company lightweight aggregate kiln site at Woodsboro, Maryland, leading to their granting permission to proceed with phase 2.

Phase 2 - Initial Cement Kiln Tests

The objective of this test was to produce initial quantities of cement clinker for analysis by Lehigh and by the Portland Cement Assocation and to make any necessary RDF feed equipment adjustments prior to conducting the extended tests. Tests were run March 6 to March 9, 1979 and on April 26, 1979. These tests produced cement under conditions of coal only (zero RDF), 19% RDF heat substitution, and 37% RDF heat substitution (average rate for test period). A follow-up test to demonstrate RDF burning to Lehigh Portland Cement Company officials and Heidelburg Cement Company officials was conducted April 26, 1979. At the same time, short tests were run at 30%, 40% and 50% RDF heat substitution.

As part of this test, detailed analysis of cement was conducted by the Lehigh Portland Cement Company and also on samples supplied to the Portland Cement Association, Skokie, Illinois.

Approval to conduct phase 3 was given by the Lehigh Portland Cement Company March 9, 1979.

Phase 3 - Extended Cement Kiln Tests

This phase included an extended test of RDF, tests of RDF characteristics, tests on cement quality and air emission testing. The tests ran from November 27 through December 23, 1979. Air emission testing was done December 5 through 14, 1979.

Phase 3 did not follow directly after the completion of Phase 2 due to a decision to install larger RDF secondary shredding equipment at the BCRRF. This equipment was in place and operating by October 1979.

Evaluation of Secondary Shredding Systems

In addition to the above work, evaluation was made of secondary shredding equipment as an amended part of this EPA grant. This work was conducted in cooperation with the Industrial Environmental Research Lab, EPA, Cincinnati, Ohio. The Project Officer for this work was Mr. Donald A. Oberacker and Michael I. Black. This work has been reported in a separate report to EPA and in a paper presented at the 1980 ASME meetings, Washington, D.C. The report and paper are included in the list of references as 6 and 7.

SECTION 5

EQUIPMENT AND PROCEDURES

RDF PREPARATION

RDF for the test program was produced at the Baltimore County Resource Recovery Facility (BCRRF) located in Cockeysville, Maryland. This facility is a joint venture of Baltimore County and the Maryland Environmental Service. Teledyne National operates the plant under contract to the Maryland Environmental Service. The facility began operating in 1976; however, since that time, many modifications have been made to the RDF processing section of the plant.

The process line for fluff RDF at the Baltimore County facility as it now exists is shown in Figure 2.

At the recovery plant, primary shredding is accomplished by two 1,000 hp, Model A-60 Tracor-Marksman horizontal hammermills. Grate holes are 15 X 30 cm. This shredding produces refuse that is roughly 85 percent less than 13 cm (5 in.) in size.

Shredded refuse is conveyed from each shredder to Dings 3-stage belt magnetic separators for the removal of ferrous metals. Each shredding line has a separate magnetic separator. Each magnetic separator contains three box electromagnets and is designed to pick ferrous metals up, then transfer the material to adjacent magnets, while momentarily allowing it to fall away from the belt to release trapped material.

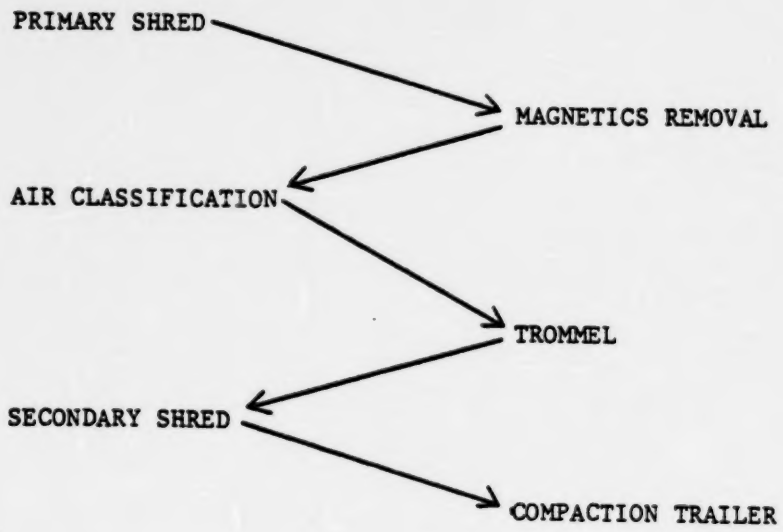

FIGURE 2. PROCESS FLOW FOR RDF PREPARATION

Following ferrous metal removal, the material from each shredder is combined on one conveyor for travel to a diverter which allows selection of all or a portion of the refuse stream for resource recovery operations. The portion selected for resource recovery is conveyed to a vertical cylinder type classifier modified from a unit manufactured by Montgomery Industries, Jacksonville Blow Pipe. The air classifier lights (which is the RDF fraction) are removed from the air classifier air stream with a cyclone and airlock feeder, then trommelled to remove grit and glass and thus decrease the ash content of the RDF material. The trommel is a Triple-S unit, 7.3-m (24-ft) length, 3.7-m (12-ft) diameter. The screen contains 3-cm round holes.

Secondary shredding for most of the tests was done with an 800 hp Williams horizontal hammermill with grate holes 3.8 X 5.4 cm in size arranged in a herringbone pattern. This shredder was designed to produce a secondary shredded RDF with a particle size roughly 95 percent less than 2.5 cm in size.

Following secondary shredding, the RDF is moved pneumatically to a compactor for loading in transfer trailers for transport to the test site.

The BCRRF processes approximately 850 tons per day of residential municipal solid waste. The RDF processing line is capable of producing about 240 tons per day of refuse-derived fuel per 14-hour work day. Additional detail on the recovery facility and associated programs for marketing recovered materials are contained in references 8, 9, 10 and 11.

RDF FEED EQUIPMENT

The RDF feed station was modified several times during the development of the RDF test program, as outlined in Section 4. Presented here (Figures 3 and 4) is the final configuration that was used to accomplish the cement kiln test burn.

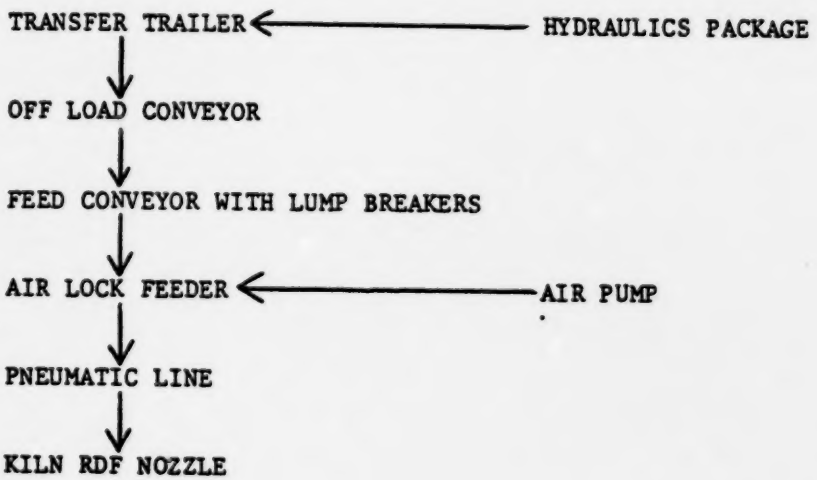

FIGURE 3. RDF FEED SYSTEM FOR CEMENT KILN

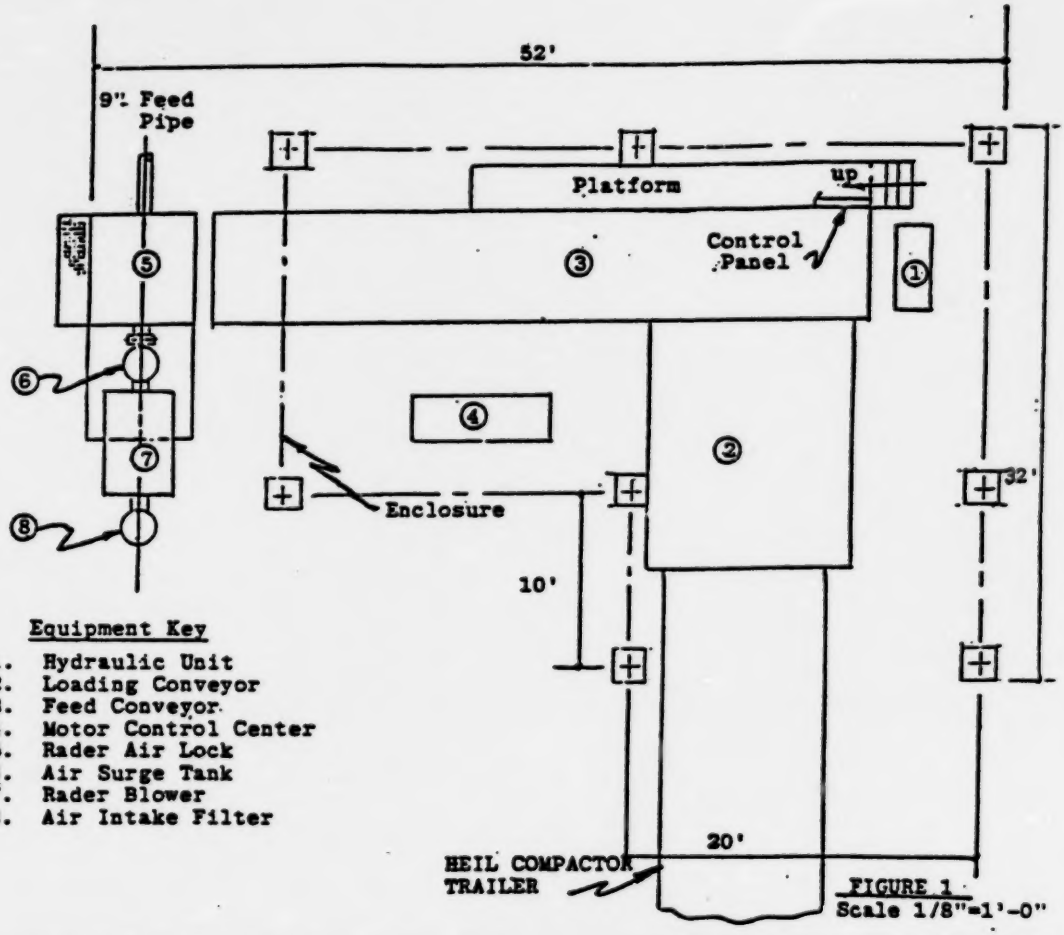

FIGURE 1
Scale 1/8"=1'-0"

FIGURE 4. RDF FEED DRAWING

RDF was delivered to the test burn site in 50 cu m (65 cu yd) Heil compactor trailers. The compaction trailers were an integral part of the feed system in that they served both for storage and a part of the feed system itself. Using a stationary hydraulic supply consisting of a 60 hp motor driving a 37 gpm 3,000 psi pump, compaction trailers were unloaded at a slow rate which was controlled by valves and on/off operation of the pump.

Transfer trailers were unloaded directly onto a wide, variable speed conveyor designed by Teledyne National. This 4.3 m (14 ft) long X 3 m (10 ft) wide flat belt conveyor had a variable speed of 0 to 6 m per minute (0 to 20 ft per minute). The off-load conveyor was inclined so that RDF discharged from the trailer was elevated and allowed to free fall from the end of the off-load conveyor through lump breakers into the feed conveyor bed. The feed conveyor was a pan type conveyor 11 m (36 ft) long X 1.2 m (4 ft) in width. This conveyor also was variable speed with speeds 0 to 6 m (0 to 20 ft) per minute. This conveyor was sized for the air lock feeder and contained two sets of rotating breakers mounted above the conveyor to smooth the flow of RDF from the off-load conveyor.

The feed conveyor again elevated the RDF so that it could be discharged by vertical free fall through a 53.3 X 88.3 cm opening into a surge chute feeding the Rader Model ESL rotary air lock feeder. The air lock feeder used four pockets, roughly 30 cm deep and 104 cm long, rotating at 28 rpm, to feed into the RDF pipeline.

Air for the pneumatic line was supplied with a Rader Pneumatics, Inc. Model 3100, positive displacement pump. The pump capacity was 4,661 cfm at 4 psi. However, it was modified with relief valves to deliver 3200 to 3600 cfm at 2 psi.

The pneumatic feed line consisted of approximately 30 m (100 ft) of 32 cm (9 in) pipe.

All RDF feed station personnel, transportation personnel and supervisors were provided by Teledyne National. The burn test feeding equipment was manned by two operators and a supervisor.

RDF SAMPLING AND ANALYSIS

The RDF was sampled and analyzed throughout the test program to provide information on heating value, moisture, and ash, and other characteristics. The analysis conducted and frequency of sampling is shown in Table 2. Most of the analyses were conducted by the Combustion Engineering Division of Penniman and Brown, Inc., 6252 Falls Road, Baltimore, Maryland 21209. Where possible, the ASTM procedure used by this firm in conducting the analysis is indicated. Particle size analysis was conducted by Teledyne National by screening in a Gilson sizing machine at the Baltimore County Material Testing Lab.

The RDF sampling procedure was modified after a draft ASTM standard dated June 12, 1978. Sampling was conducted at the RDF feed station. Grab samples were taken from the back, middle, and forward of the load as unloading occurred. These were accumulated in double 4-mil plastic bags. Approximately 4.5 kg of material was taken from each truckload.

Prior to chemical analysis, the size of each sample was reduced and the material was milled by Teledyne personnel at the Baltimore County Resource Recovery Facility.

Each whole grab sample was milled through 6-mm and 2-mm screens, quartered, and delivered to Penniman and Brown in double 4-mil plastic bags.

TABLE 2. RDF SAMPLING AND ANALYSIS

Analysis	ASTM Standard or Other Procedure	Sampling Frequency	
		Each Truck Load	Occasional
Heating Value	D2015-71	X	
Moisture	D3173-73	X	
Ash Content	D3174-73	X	
Fixed Carbon	D3172-73		X
Volatile Matter	D3175-77		X
Sulfur	D3177-75		X
Total Aluminum	-		X
Metallic Aluminum			X
Particle Size Distribution	Gilson sizing machine		X

CEMENT KILN

The cement kiln tests were conducted at the Lehigh Portland Cement Company plant at Union Bridge, Maryland. This dry-process plant (raw materials are ground dry) has a production capacity of 2850 tons per day of cement clinker using four kilns. Three kilns were constructed in 1957, with capacities of 700 tons per day each; the other was constructed in 1970, with a capacity of 750 tons per day.

The principal raw materials for the Union Bridge plant are limestone, sand, and shale. Limestone and shale are taken from a quarry near the plant, while sand is purchased from suppliers in Maryland and Virginia. The raw materials are trucked to the plant and dumped into the hopper of a Gyratory crusher where they are broken down to pieces less than 15 cm (6 in.) in size. The crushed material is conveyed to a surge bin that provides feed for two cone crushers. The cone crushers, in conjunction with vibratory screens, produces a material that is finer than 2.5 cm (1 in.). The cone crushers have a capacity of 900 tons per hour each. This material travels to a storage system by conveyor.

Raw materials are stored in a 276 X 28 m (907 X 92 ft) storage building which contains separate sections for the storage of crushed limestone, sand, shale and mill scale (ferric oxide). Storage sections are also provided for the cement clinker and gypsum which are ground together to provide the finished product.

In assembling the raw materials, crushed limestone, sand, shale and mill scale are transported from the storage bins to raw material bins by traveling cranes. Proportioning feeders deliver selected amounts of materials to the raw materials mill.

Both drying and pulverizing are performed at the raw grinding mill. An oil-fired furnace, prior to the inlet of the raw mill, dries the incoming material. It is then crushed between steel balls in the grinding mill. An air classifier separates materials that are fine enough to be used in

the cement making operation from too coarse material that must be reground in the mill. The raw material is sized so that 84 percent will pass through a wire mesh screen with 15,750 holes per sq cm. The raw grinding mill is powered by a 3,500-hp motor and has a capacity of 220 tons per hour. The proper mix of raw materials is accomplished by using 18 blending bins with capacity of 225 tons each and 18 reblending bins also with a capacity of 225 tons each. Material is selected from these bins according to composition determined with samples taken when the material was placed in the bins, and is then mixed to provide the final raw material mix to the kiln.

Screw feeders supply a constant rate of material to the kilns. As the material moves through the kiln, calcining (the removal of carbon dioxide from lime) and clinker formation occur. The raw materials combine in this process to form a new set of compounds and are transformed into a hard, glossy material called portland cement clinker.

From the kiln, clinker drops into a traveling grate cooler where air blows through the clinker. This air is collected and recycled as the primary air stream for the coal feed system and as secondary air for combustion. After passing through the cooler, the clinker material moves on drag chains to conveyor systems and storage.

The clinker-grinding section of the plant contains a large mill which grinds a majority of the cement and two smaller mills for special high-fineness types of cement. In this process, gypsum is mixed with the cement to control the rate at which it will set. Scales continuously weigh and proportion the two materials as they are fed into the mills.

The finish-grinding mills use steel balls as the grinding media. These are used in series with an air classifier which removes coarse particles that are returned to the mill for additional grinding and sends the finished cement on to storage silos.

The main finish mill is a two-compartment, 4.6 m (15-ft)-diameter mill, powered by a 3,500-hp motor. The capacity of this mill is 80 TPH. The two smaller mills are 3 m diameter and are powered by 1,250-hp motors. The capacity of these mills is 25 TPH thus a total capacity of 130 TPH.

The No. 4 kiln was used for testing RDF; the main reason being its proximity to a suitable site for the RDF feed station. The No. 4 kiln has a 700-ton-per-day capacity. It is 121 m (400 ft) long, 3.5 m (11.5 ft) in diameter, and rotates 65 to 85 revolutions per hour on an inclined axis elevated 5.2 cm per meter linear distance.

Raw materials are fed in at the elevated end of the kiln; fuel is injected at the lower end. Consequently, raw materials travel counter to the flow of heat and gases through the kiln. The nozzle for feeding pulverized coal into the kiln is located at about the center of rotation of the kiln.

The normal fuel for the plant is Pennsylvania bituminous coal. The coal is crushed in a ball mill and blown into the kiln through a 30 cm (12-in.) diameter nozzle using preheated air.

To feed RDF into the test kiln, the Lehigh Portland Cement Company installed a second nozzle extending into the kiln parallel to and under the coal nozzle. RDF suspension time would have been increased by aligning the RDF feed nozzle above the coal nozzle; however, the kiln hood design prevented this arrangement from being used. RDF was conveyed to the nozzle pneumatically with about 3,200 ascfm air at a feed rate of 3.5 ton per hour (30% RDF kiln heat). The RDF nozzle initially installed was 23 cm (9 in.) in diameter; this was replaced after preliminary tests as explained in the Results and Discussion section by a 17.8 cm (7 in.) diameter nozzle for the final cement kiln tests.

RDF was fed into the kiln at a constant rate from the RDF feed station. All adjustments in kiln operation were made by the operators using the coal feed system.

CEMENT SAMPLING AND ANALYSIS

Cement analysis was done by both the Portland Cement Association (PCA) and the Lehigh Portland Cement Company. All sampling and orders for analysis were made by Lehigh personnel.

The Lehigh Portland Cement Company is equipped with all equipment necessary for major testing of the cement product. Quality control tests, as well as chemical analysis tests, are performed using x-ray analysis. Table 3 lists various types of analysis performed by the Lehigh Portland Cement Company.

Analyses by the Portland Cement Association consisted primarily of microscopic analyses, x-ray diffration, Ono analyses (predictions of cement strength), and detailed chemical analyses.

To obtain cement for analysis, clinker from about 6 hours of production (160 tons) was stored separately after leaving the kiln and clinker cooler. When sampling was to be done, the finish mill bin was allowed to run empty and the stored test pile was tipped into the bin. The finish mill was then run for two hours to clear out all contamination from the previously milled clinker. Sampling was then done at 3, 4, and 5 hours after the start of milling. Samples were taken directly from the stream going from the mill to a storage silo.

AIR POLLUTION CONTROL EQUIPMENT AND AIR EMISSIONS ANALYSIS

Air pollution control equipment on the No. 4 kiln consisted of two parallel Buell Engineering electrostatic precipitators (ESP) (Model 13GA-400-414 dual unit). Total flow rate through the dual unit system was 120,000 acfm at 345°C. The two ESP's exhaust to a common stack 3.4 m (11.3 ft) in diameter and 10.7 m (35 ft) tall. All sampling and measurements were conducted on the circular flue stack through four equally spaced

TABLE 3. PHYSICAL AND CHEMICAL ANALYSIS OF CEMENT

Compressive Strength

- 3-day, 7-day, and 8-day test

Fineness

- % passing 325 mesh sieve
- Blaine (surface area)
- Wagner (surface area)
- % retention-alpine sieve

Autoclave expansion

Time of set

- Gilmore
- False set

Chemical

- SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3
  ignition loss, insoluble residues, Free CaO.
- Alkalinity - K_2O, Na_2O

X-ray Diffraction

- Tricalcium aluminate - C_3S
- Tricalcium silicate - C_2S
- Calcium aluminoferrite - C_3A
- Dicalcium Silicate - C_2S

sampling ports located approximately 4 m (13 ft) below the stack exit and approximately 9 m (30 ft) above the nearest upstream obstruction. A large all-around platform located approximately 1 m below each of the sampling ports provided access for sampling. Figure 5 illustrates the ESP/kiln arrangement. No suitable sampling location was available at the inlet to the precipitators because of their close proximity to the end of the kiln. Therefore, all sampling was done after gases were cleaned by the precipitator.

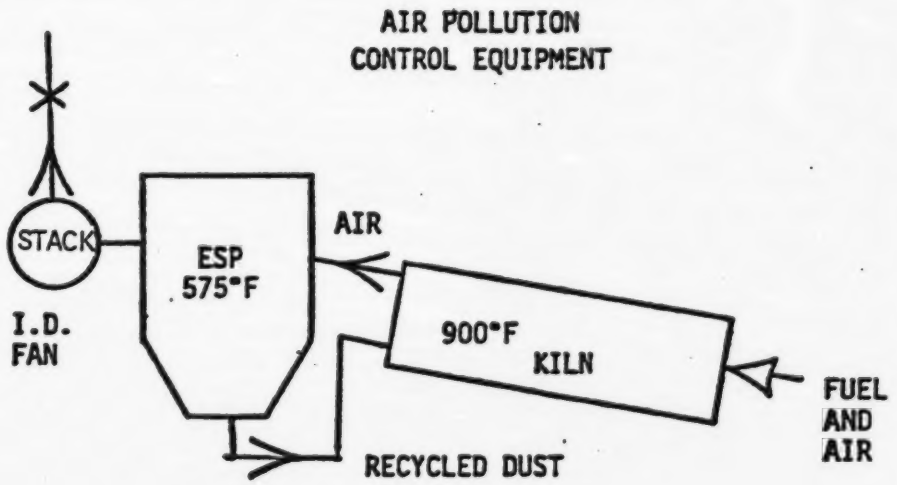

FIGURE 5. ELECTROSTATIC PRECIPITATOR-KILN ARRANGEMENT

Proposals were requested from three firms for air emissions analysis. The following firm was selected to perform the work.

TRW
Environmental Engineering Division
3200 East Chapel Hill Road
Research Triangle Park
Chapel Hill, North Carolina 27709

Seven air emission sampling runs were made by TRW on 7 of the 10 days. Sampling and analytical procedures used by TRW are listed below. For particulate analysis, the cross section of the stack was divided into 40 equal areas, and particulate sampling was carried out for three minutes at the centroid of each area.

1. Sampling and Velocity Traverse: EPA reference method 1. Total of 40 calculated sampling traverse points.

2. Determination of Flue Gas Velocity and Flow Rates: EPA reference method 2.

3. Determination of Dry Molecular Weight of Stack Gas: Calculated from gas composition measured by gas chromatography with a thermoconductivity detector. Carle model 8700, flow rate of 22 milliliters per minute and 0.02% sensitivity.

4. Determination of Stack Gas Moisture: From condensate obtained in particulate sampling.

5. Particulate Emissions: EPA reference method 5. Impinger solid collections are included after subtracting the weight of sulfuric acid formed ($H_2SO_4 \cdot 2H_2O$). The sulfuric acid determination was made by Barium Chloride titration.

6. Determination of SO_3 - SO_2 (SO_x): EPA reference method 6. The larger Greensburg-Smith impingers were used instead of the midget type. SO_x analyses were made by Barium Chloride titration.

7. Determination of NO_x (NO - NO_2) Emissions: Direct reading from a calibrated chemiluminescent gas analyzer. Thermo-Electron Model 10AR with 0.1 ppm sensitivity, flow rate of 40 cc/min., Span gas of 248 ppm NO.

8. Chloride Determination (as HCl): Analysis on particulate impinger solution by a Specific Ion Electrode, Orion Ionanalyzer/Model 407A.

9. Stack Plume Opacity: Visual readings taken by an experienced observer for a 30-minute period during each test run, as suggested by Mr. R.E. Lipinski from the Air Quality Programs, State of Maryland.

Process information recorded during emission tests included: fuel input rates recorded hourly, percent oxygen in the kiln exit gases, percent combustibles in kiln exit gases, kiln temperature, exit gas temperature, kiln inlet and outlet drafts, precipitator operating parameters, and water spray flow rate at the exhaust end of the kiln.

SECTION 6

RESULTS AND DISCUSSION

PHASE I - EQUIPMENT DEVELOPMENT AND DEMONSTRATION

This phase included:

- o development of RDF acceptable for use in a rotary kiln
- o development and demonstration of RDF feed equipment
- o demonstration of RDF burning.

The work was carried out at the Baltimore County Resource Recovery Facility (BCRRF), Cockeysville, Maryland and at the No. 2 kiln at the Lehigh Portland Cement Company's lightweight aggregate (LWA) plant at Woodsboro, Maryland. Although the kiln was not identical to a cement kiln, it provided a location for tests where the product being produced was not likely to be affected by the use of RDF.

RDF Feed Station Design and LWA Kiln Tests

Previous Work --

A semi-portable RDF feed system designed and constructed by Teledyne National as part of the Baltimore County/MES Market Development Program was used to conduct tests at the LWA kiln in February and March of 1977. (The feed equipment design, which included secondary shredding and a fan-powered pneumatic system, and tests are discussed in more detail in Appendix A.) The purpose of the tests was (a) to give plant engineers an opportunity to observe the burning characteristics of RDF, (b) to learn to operate a kiln with respect to these characteristics, (c) to demonstrate equipment

reliability for the RDF feed station, and (d) to determine what size RDF would burn satisfactorily in suspension in the kiln.

In February 1977, nine tests were conducted using a total of 67 tons of refuse-derived fuel. During these tests, different grate sizes (RDF particle sizes), RDF nozzle positions and kiln control settings were tried to determine the best combination for burning refuse-derived fuel. In March, an additional 150 tons of RDF were burned.

During this work, the proper adjustments in kiln operation and RDF feed system and the necessary RDF size were determined so that RDF ignited in the proper burning zone in the kiln and produced an acceptable LWA product.

The RDF feed system suffered from several operational problems, including the following:

(1) Shredder maintenance was high because of the fine particle size required and maintenance was difficult to carry out at the test site.

(2) The use of a fan to power a pneumatic delivery of the RDF resulted in excess amounts of air being blown into the kiln.

(3) Fan blade wear was excessive and a high maintenance problem.

(4) There were problems with avalanching of material from transfer trailers into the feed conveyors and bridging of material in the conveyors resulting in the formation of lumps and periodic jamming of the feed equipment.

Current Work --

As a result of these problems, it was decided to move the secondary shredding operation to the BCRRF at Cockeysville, Maryland, where

maintenance could be performed efficiently, and to modify the feed equipment to the arrangement described in Section 5, Equipment and Procedures. The modifications included use of a positive displacement pump to drive the pneumatic system, and installation of lump breakers along the feed conveyor into which transfer trailers were unloaded, and the addition of a wider variable-speed conveyor for better controlled RDF unloading.

This equipment tested out satisfactorily in a 7-day run at the lightweight aggregate kiln October 13 through 20, 1978. Following this test, the feed station was moved to the Lehigh Portland Cement Company kiln at Union Bridge, Maryland.

RDF Particle Size

During the equipment trials described above, four shredder grates, with 10.0 (4-in.), 3.8 (1-1/2 in.), 2.5 (1-in.), and I.3 (1/2-in.) cm holes, were tried with a Grundler Model 56-40 shredder so that operating engineers at the kiln could evaluate the burning characteristics, particularly the ability to burn in suspension, of various size ranges of RDF. It was recognized that the flame pattern in the LWA kiln was not identical to that in the cement kiln (the flame is aimed more at the kiln bed and the burning zone is shorter); however, it was felt that RDF that burned satisfactorily in the LWA kiln would probably be suitable for use in the cement kiln.

The grate with 2.5-cm (1-in.) holes was eventually selected for producing RDF for the test. Engineers at the kiln felt that material shredded with larger holes was too large to burn properly in suspension. Teledyne engineers found that the smallest grate size, 1.3-cm (1/2-in.) hole, caused severe hammer wear and reduction in shredding capacity of the system.

Later in the test program, prior to conducting Phase 3 described below, an 800-hp Williams secondary shredder was installed to increase secondary shredding capacity. Grates for this shredder contained herringbone pattern holes 3.81 X 5.38 cm in size. Particle size

distribution for this shredder with new hammers is indicated in Table 4 in comparison to the Grundler shredder with 2.5 cm grates. Some variation in particle size would occur with hammer wear. No tests were conducted to monitor this change.

As indicated, RDF material for the kiln was roughly 95% less than 2.5 cm (1-in.) in size.

TABLE 4. PARTICLE SIZE DISTRIBUTION OF SECONDARY SHREDDED RDF (NEW HAMMERS)

Screen Size cm	% Passing through Screen	
	Grundler Shredder	Williams Shredder
7.6	100	99
5.0	100	98.5
2.5	95	94
1.3	51	84
1.0	17	57

NOTE: Source of material for shredders was residential MSW primary-shredded by 1000 hp Model A-60 Tracor-Marksman horizontal hammermills to roughly 85% less than 12.7 cm (5 in.).

PHASE 2 - INITIAL CEMENT KILN TESTS

The objective of this test was to produce quantities of cement clinker and finished cement for analysis and to make any necessary RDF feed equipment adjustments prior to conducting the extended tests. Tests were run March 6-March 9, 1979, followed by a demonstration burn on April 26.

March 6 - 9, 1979

The test burning of RDF began March 6 at 3:45 pm to check on the operation of RDF feed equipment, to adjust the position of the fuel nozzle and to line out kiln operations with regard to the burning of RDF. All of these were accomplished within two hours. The tests were restarted at 7:50 am, Tuesday, March 7. The RDF feed rate was varied at the direction of Lehigh during March 7 and 8. At 3:45 pm, March 8, the feed rate was increased to give a burning rate in the range of 30 to 37 percent RDF heat contribution. This rate was continued until 5:20 pm, Friday, March 9, when the test was terminated.

During the course of this test, several brief shutdowns of RDF feed were experienced; however, none of these are believed to have seriously affected the tests. The shutdowns were as follows:

(a) 1 hour 15 minutes shutdown, starting at 0200 hours March 8 - unusable hydraulic connection on RDF trailer

(b) 15-minute shutdown, starting at 0440 hours March 9 - out of RDF

(c) 25-minute shutdown, starting at 0825 hours March 9 - out of RDF

(d) 1.9-hour shutdown, starting at 1005 hours March 9, cement kiln ID fan failure.

Tables 5 and 6 give the amounts of RDF and coal burned and the RDF heat input to the kiln during the March 6 - 9 tests. The amount of coal burned was determined from coal feeder readings taken each time RDF burning was started or stopped. RDF could only be determined on an average trailer load basis since no in-line weighing capability existed in the RDF feed system. This was a disadvantage as far as control was concerned; but overall, the lack of this capability probably did not seriously affect the test.

Clinker was saved for analysis in accordance with procedures described in Section 5 during the following times:

(a) 4:30 am - 10:00 am March 8 - average RDF heat input 18.9 percent

TABLE 5. RDF AND COAL BURNED - MARCH 6 - 9 TEST

Start Date	Load	Start Time	Stop Time	RDF Burned (ton)	Time Burned (hours)	Coal Burned (ton)
3/6	1	1545	1040*	9.04	4.83	20.05
3/7	2	1040	1730	11.23	6.83	27.15
3/7	3	1730	0200*	10.27	8.50	35.15
3/8	4	0350	1215	16.24	8.42	35.55
3/8	5	1215	1800	12.86	5.75	23.40
3/8	6	1800	2200	11.01	4.00	14.35
3/8	7	2200	0130	10.05	3.50	12.60
3/9	8	0130	0440*	10.97	3.17	11.40
3/9	9	0455	0825	11.76	3.50	12.25
3/9	10	0850	1430*	11.91	3.75	13.65
3/9	11	0430	1720	7.71	2.83	10.20
TOTALS				123.25	55.08	215.75

*Burning not continuous between start and stop time; see text for details.

TABLE 6. RDF HEAT INPUT TO KILN - MARCH 6 - 9 TEST

Start Date	Load No.	RDF* Heat Btu/lb. (million)	Coal** Heat Btu/lb. (million)	Total Heat Btu (million)	RDF Heat Contribution %
3/6	1	116.9	506.9	623.8	18.7
3/7	2	152.0	686.4	838.3	18.1
3/7	3	122.5	888.6	1011.1	12.1
3/8	4	209.4	898.7	1108.1	18.9
3/8	5	181.3	591.6	772.8	23.5
3/8	6	141.3	362.8	504.1	28.0
3/8	7	144.3	318.5	462.9	31.2
3/9	8	149.6	288.2	437.8	34.2
3/9	9	158.9	309.7	468.5	33.9
3/9	10	201.9	345.1	547.0	36.9
3/9	11	117.8	257.9	375.7	31.4

* Heat value based on actual RDF analysis.

** Heat value based on monthly assay from Lehigh Portland Cement Company - 12,640 Btu/lb.

(b) 7:00 - 10:00 am and 12:30 - 3:00 pm March 9 - average RDF heat input 36.9 percent

(c) March 11, 6 hours of production - zero RDF input.

RDF Analysis

Results of analysis for heating value, ash and moisture content on samples from each load of RDF are presented in Table 7. Average values for the 11 loads of RDF are: (a) heating value - 6811 Btu per pound, (b) moisture - 19.3 percent, (c) ash - 10.3 percent.

TABLE 7. RDF HEATING VALUE, ASH CONTENT, AND MOISTURE - MARCH 6 - 9 TEST

	As Received			Dry	
Load	Moisture %	Ash %	Heating Value Btu/lb	Ash %	Heating Value Btu/lb
1	19.2	10.0	6466	12.4	8004
2	15.6	7.7	6766	9.1	8016
3	25.2	11.4	5963	15.2	7970
4	16.5	11.5	7181	13.7	8604
5	19.1	7.9	5924	9.7	7324
6	17.2	15.1	7047	19.0	8510
7	24.6	13.6	6417	18.0	8505
8	12.8	8.2	7832	9.4	8485
9	21.8	11.7	6818	14.9	8720
10	24.9	9.4	6754	12.5	8998
11	15.0	6.8	7755	8.1	9127

Because of the trommeling step in the BCRRF production line for RDF, which removes considerable amounts of glass and grit, RDF from the facility is consistently high in heating value and low in ash. In addition to the analysis in Table 6, approximate analysis on a composite sample of all loads of RDF was run. This gave the following results:

	As Received	Dry Basis
Volatile Matter, %	69.4	77.6
Moisture, %	10.6	-
Fixed Carbon, %	12.4	13.9
Ash, %	7.6	8.5
Heating Value, Btu/lb.	7692	8602
Total Sulfur, %	0.19	0.21

In addition, an analysis was performed for metallic and total aluminum on each of the 11 samples of RDF. Metallic aluminum ranged from zero to 0.03 percent by weight of the total sample and did not appear to be any problem as far as the cement manufacturing process is concerned. Results of these analyses are included as Appendix B.

There was some difficulty in scheduling shipments of RDF for the initial test; however, these problems were worked out before conducting the extended tests in Phase 3.

Effect of RDF on Cement Quality

Cement samples were analyzed by both the Lehigh Portland Cement Company and the Portland Cement Association.

Results of physical and chemical tests by the Lehigh Portland Cement Company are summarized in Table 8. The table also shows corresponding American Society of Testing and Materials (ASTM) standards where they apply. The average rates of RDF heat input during the sampling periods were 0, 18.9, and 36.9 percent.

TABLE 8. PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT CLINKER - MARCH 6 - 9 TEST

Analysis	% RDF Heat Contribution			ASTM Standard*
	0	19	37	
Compressive Strength				
3-day	3820	3620	4000	(1800)
7-day	4650	4830	4870	(2800)
28-day	5920	6200	5800	(4000)
Fineness				
% Passing 325 Mesh	95.12	95.7	95.6	
Blaine, Surface Area, cm^2/gm	3940	4050	4180	
Wagner, Surface Area, cm^2/gm	2160	2300	2260	
% Retention Alpine (Sifter)	20.2	17.2	17.8	
Autoclave Expansion, %	0.690	0.211	0.371	(0.80)
Time of Set				
Gilmore - Initial (hr:min)	3:00	2:40	2:10	(1.00)
Gilmore - Final (hr:min)	5:40	5:10	5:25	10:00
Fed. False Set, %	94	84	86	

(continued next page)

TABLE 8. PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT CLINKER - MARCH 6 - 9 TEST (continued)

Analysis	% RDF Heat Contribution			ASTM Standard
	0	19	37	
Chemical				
SiO_2	19.82	20.84	20.44	†
Al_2O_3	4.94	5.29	5.04	†
Fe_2O_3	2.76	2.41	2.60	†
CaO	64.53	64.35	63.69	
MgO	4.00	3.25	3.50	5.6%
SO_3	2.67	2.41	3.00	3.5
Ignition Loss	0.70	0.76	0.73	3.0
TOTAL	99.47	99.31	99.00	
Insoluble Residue	0.10	0.25	0.24	.75
Free CaO	2.14	1.13	0.95	
Alkalinity				
K_2O	0.69	0.72	0.90	
Na_2O	0.06	0.11	0.14	
Na_2O Equivalent	0.51	0.58	0.73	#

*For Type I cement, parentheses denote minimum value, others are maximum.

†None for Type I.

#Not critical for use in the Lehigh market area; standard is 0.6.

These results show that:

- o cement strengths exceeded ASTM minimum standards and were not greatly changed by burning RDF

- o physical characteristics such as fineness, autoclave expansion, time of set, and ether properties were within the proper range and not adversely affected by burning RDF

- o chemical composition remained about the same regardless of the use of RDF as a supplementary fuel.

Additional analyses by the PCA, which included x-ray fluorescence (for heavy metals), microscopic observation, Ono analysis (a prediction of cement strength) and x-ray diffraction, also confirmed, for the most part, that RDF did not have any detrimental impact on cement strength or chemical composition. The analyses did, however, indicate a problem with combustion of RDF in suspension. The PCA conclusions were:

> "The amounts of heavy metals found in the clinkers were very low and it does not appear that these elements will cause problems in practice. No certain estimate of metallic aluminum could be made, but it seems likely that its concentration was negligible. The RDF clinkers were of poor quality, mainly because of poor control in the burning zone of the kiln. The burning zone should always be maintained in an oxidizing state (at least 1 percent excess O_2) and none of the RDF should be allowed to fall onto the clinker before being thoroughly burned. If the burning conditions are improved, it seems to us that good quality clinker will result."

The PCA report is included as Appendix C.

The problem indicated in the PCA analysis was that some RDF was not burned in suspension and dropped to the bed of the cement kiln, resulting in a depletion of oxygen at the kiln bed, the development of reducing conditions, and formation of lower quality crystalline characteristics in

clinker than are desired. The step taken to correct this situation was to replace the existing RDF nozzle with one of a smaller diameter to increase the velocity of injection of RDF and thus increase its time in suspension and the length of the firing zone. The replacement nozzle was 17.7 cm (7 in.) diameter versus the original of 22.9 cm (9 in.).

April Demonstration Burn

On April 26, 1979, RDF was burned as a demonstration for officials of the Lehigh Portland Cement Company and the parent company, Heidelburg Cement and, at the same time, the firing characteristics of the smaller diameter RDF nozzle were observed. In this demonstration 34.6 tons of RDF were burned between 7:30 am and 6:00 pm.

Most of the demonstration tests were run at 30 percent RDF heat. Although no detailed chemical analyses were made of the cement, the RDF appeared to burn satisfactorily in suspension with the smaller nozzle. Near the end of this test, several short runs were made with increased levels of RDF input, approximately 40 and 50 percent heat contribution. At the 40 percent level, RDF also appeared to burn satisfactorily in suspension; however, at 50 percent there was drop-out and flaming pieces and RDF appeared to burn on the bed. There was also decreased visibility into the kiln. Since a few hours of operation is not enough to stabilize for clinker testing because of the slow redistribution of ash throughout the kiln and electrostatic precipitator system, no cement analysis was performed during the April 26 tests.

Following these tests, permission was received from Lehigh to proceed with the extended cement kiln tests.

PHASE 3 - EXTENDED CEMENT KILN TEST

This test was run November 27 to December 23, 1979, burning 1,272 tons of RDF for an average heat contribution of 30% (approximately 3.5 tons per hour).

The tests required 95 trailer loads of RDF, which averaged 13 tons per load. Each truck was sampled and the RDF was analyzed for heating value, moisture, and ash. RDF was burned November 27 through December 4 and December 11 through December 23. Air emission testing was performed December 5 through December 14.

RDF was burned a total of 178 hours during the first part of the test, averaging 3.38 tons per hour, and 183 hours during the second part of the test December 11 through December 23, averaging 3.67 tons per hour.

. Although the RDF feed equipment operated reliably throughout the test, shutdowns were necessary due to problems with the kiln and clinker cooling equipment. The kiln was nearing the repair portion of its operate-repair cycle and was scheduled for shutdown for routine maintenance on December 24. The kiln, therefore, was not in the best physical condition at the time the tests were conducted. The major interruptions are listed below.

- November 30 - 15 hours (1.25 days); replace kiln nosebrick
- December 2 & 3 - 30 hours; replace kiln nosebrick
- December 18 - 18 hours; repair clinker cooling
- December 19-22 - 74 hours (3 days); rebrick part of kiln

The RDF heat contribution during the test for each day, or partial day burning RDF is listed in Table 9. The average heat contribution to the kiln during the test was 30.5%. RDF heat input to the kiln was calculated in the same manner as indicated for the March 6-9 test.

The results of analysis of RDF samples from each trailer load of material are presented in detail in Appendix B. The average values were:

(a) Heat value - 6440 Btu/lb
(b) Moisture - 20.4%
(c) Ash - 11.8%

TABLE 9. COAL AND RDF USED DURING EXTENDED TESTS

Date	Coal Usage Daily Totals (Ton)	RDF Usage Daily Totals (Ton)	Total Heat (Million Btu)	RDF Heat Contribution (%)
11-27	72.70	61.5	799.5	31.17
11-28	72.85	59.0	767.0	30.78
11-29	106.0	92.3	1199.9	32.35
11-30	42.55	31.8	413.4	29.10
12-1	105.95	74.2	964.6	27.78
12-2	99.10	68.5	890.5	27.51
12-4	87.35	63.0	819.0	28.37
12-5	106.00	82.2	1068.6	29.87
12-6	89.20	70.3	913.9	30.21
12-11*	30.80	20.5	266.5	25.96
12-12	32.60	26.7	347.1	30.14
12-13	105.30	91.5	1189.5	31.40
12-14	104.20	90.7	1179.1	31.43
12-15	105.95	90.7	1179.1	31.11
12-16	109.30	90.9	1181.7	30.46
12-17	103.85	74.1	963.3	27.32
12-18	84.55	63.2	821.6	28.25
12-19	43.85	41.7	542.1	33.37
12-20	26.15	25.5	331.5	33.93
12-23	44.50	53.7	698.1	38.6
TOTAL	1721.4	1397.1	18,162.3	30.53

*Coal only for emissions testing 12-7 to 12-10.

Although ash and moisture are slightly higher than the March test and heating value somewhat lower, this material still had characteristics of an excellent quality RDF material.

Air Emission Tests

The Introduction, Summary and Discussion sections of the report prepared by TRW, Environmental Engineering Division, Research Triangle Park, North Carolina, for the cement-kiln emissions test are included in this report as Appendix D.

The planned procedure for emmission testing was to conduct three runs with RDF and coal, starting December 5, followed by three runs with coal only. This plan, however, was disrupted when on December 5. during the first test run, the precipitator malfunctioned. Due to this, testing was suspended temporarily while the precipitator was repaired. In addition to repairs, the precipitator was also cleaned of dust and fly ash. A decision was then made to reverse the order of the test, running coal only first, followed by coal and RDF. On December 10, test crews returned and conducted, between December 10 and 14, six test runs on emissions. In addition, emission tests were conducted during a special test by Lehigh Portland Cement using a high volatile coal with 4 to 5% sulfur, compared to the normally burned 2.5 to 3% sulfur, low volatile coal.

Operating conditions during the test are given in Table 10; results in Table 11.

Unfortunately, it appears that the kiln and precipitators were not at equilibrium conditions during the test period, due to the shutdown and cleaning just prior to starting the test. An indication of this is given by the fact that sulfur emissions were higher while burning coal (4% to 5% sulfur) than when burning coal and RDF (0.2% sulfur). Nevertheless, the results are somewhat reassuring regarding the potential for emission problems:

TABLE 10. OPERATING CONDITIONS AND FUEL FEED DURING EMISSIONS TEST RUNS

	TEST RUN NUMBER					
	Coal Only			RDF and Coal		
	2	3	4	5	6	7
Date	12/10	12/10	12/11	12/13	12/13	12/14
Test Time, start	0918	1211	0950	0840	1412	0801
end	1131	1426	1206	1049	1624	1026
Product Rate, ton/hr	29.2	29.4	28.9	25.1	27.1	29.2
Kiln, RPM	84	84	82	71	78	82
Coal Fuel Rate, #/hr	12,200	12,770	11,800	8,600	8,430	8,500
Coal Fuel Type*	R/H-V	H-V	H-V	H-V	H-V	H-V
RDF Fuel Rate, #/hr	0	0	0	7,209	9,366	7,963
% RDF by Btu Value	0	0	0	30.6	37.4	33.0
Kiln, Oxygen, %	3.2	2.8	2.6	3.0	2.3	3.0
Kiln End Water Spray (Gallons per Minute)	26	26	23	31	34	30

*R = Regular, H-V = High Volatile Coal

TABLE 11. CEMENT KILN EMISSIONS

	TEST RUN NUMBER					
	Coal Only			RDF and Coal		
	2	3	4	5	6	7
Flue Gas						
Temperature, °F	485	486	483	485	500	493
Flow rate, DSCFM	49,150	53,390	50,190	45,680	49,340	43,760
Water vapor, % by vol.	15.05	14.60	13.47	19.32	19.33	20.95
Stack opacity, %	2.6	17.0	9.8	21.6	16.8	16.6
Particulate Matter						
Concentration, grain/DSCF	0.0128	0.0221	0.0331	0.0474	0.0801	0.0495
Chloride Emissions as HCl						
HCl, ppm (dry)	7.47	191	77.8	155	223	242
Sulfur Oxides Emissions						
SO_3, ppm (dry)	3.0	2.5	9.3	4.1	25.4	7.1
SO_2, ppm (dry)	19.7	34.3	235	1,050	353	444
Nitrogen Oxides Emissions (as NO_2)						
NO_x, ppm (dry)	135	295	112	72	130	160
Stationary Gas Analysis (dry)						
CO_2, %	10.7	10.1	14.2	11.4	11.6	12.6
O_2, %	13.8	13.6	9.9	11.1	11.5	11.9
CO, %	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
N_2, % by difference	75.5	76.3	75.9	77.5	76.9	75.5

- o Particulates were somewhat higher when burning RDF, however, the emission levels would meet standards in many areas of the country.

- o Chlorides, as indicated by HCl, may have increased some while burning RDF, but were not at a level that would be considered a problem.

- o Nitrous oxides may have decreased slightly while burning RDF.

- o Sulfur, even with the results, was well below the State's 2000 parts per million standard for this plant. An explanation for this is suggested in the report by TRW (in Appendix D).

Effect of RDF on Cement Quality

Table 12, which provides a comparison of physical and chemical properties of Type II cement produced during the extended test (using RDF) with a regular production (100% coal fired) Type II cement, shows the RDF cement to be comparable in quality to regular production cement of this type. These data were backed by the following statement from the Lehigh Portland Cement Company.

> "The Type II cement which was made at our Union Bridge plant from clinker produced using approximately 30% RDF was similar in quality to Type II cement of similar chemical composition made with 100% coal. We did not see a detrimental effect on compressive strengths or other properties in this RDF cement."

Samples of control and "30% RDF" heat clinker were given to the Portland Cement Association for analysis. These analyses also did not reflect any real detrimental effect of RDF on the cement quality. Their summary of the results is given below:

> "The chemical analyses show little difference between the RDF clinkers and the "control" clinker, but the microscopic evaluation shows the two RDF clinkers to be of somewhat lower

TABLE 12. PHYSICAL AND CHEMICAL PROPERTIES OF TYPE II CEMENT PRODUCED DURING EXTENDED TEST

Analysis	Type II Cement 30% RDF Heat	Type II Cement 100% Coal	ASTM Standard*
Compressive Strengths, psi			
3-day	2670	2770	(1500)
7-day	3600	3630	(2500)
28-day	5050	5030	(4000)
Finess, Blaine, cm2/gm	3540	3710	-
Chemical, %			
SiO_2	22.0	21.7	(21.0)
Al_2O_3	4.6	4.8	6.0
Fe_2O_3	2.7	3.3	6.0
CaO	62.4	62.0	-
MgO	3.0	3.4	6.0
SO_3	3.1	2.8	3.0-3.5†
Ignition Loss	1.4	0.7	3.0
X-ray Diffraction, %#			
C_3S	44	43.0	-
C_2S	30	30	-
C_3A	7.6	7.3	8.0
C_4AF	8.2	9.9	-

*For Type II cement; numbers in parentheses are minimum values, other are maximum.

†See ASTM standards.

#Analysis for tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite plus twice the tricalcium aluminate.

quality than the control. However, the differences between the two RDF clinkers are at least as great as the differences between them and the "control" clinker. Localized reducing conditions were found to a limited extent in all three clinkers, but were most severe in the composite clinker, PDE-14. The results suggest that differences between the clinkers are attributable to slight changes in burning conditions.

No metallic aluminum was detected in any of the clinkers, either by microscopy or by a qualitative chemical technique using a large sample. It was not deemed necessary to attempt a quantitative measurement, since the technique is still not considered very reliable. However, it appears that no significant level of metallic aluminum is present in the clinker samples that we tested."

This summary is based on an analysis of three clinker samples, one, PDE-14, being a composite of material taken at the kiln hood, without the benefit of proper clinker cooling which could affect the results observed. The opinion of the Union Bridge plant manager, Mr. Robert Durcock, was that the PCA tests did not show any sign of detrimental effects of RDF on the quality of cement produced at the plant.

Further evidence in support of the positive results of the tests is the willingness of the Lehigh Portland Cement Company to engage in further discussions of the possible long-term use of RDF as a supplementary fuel.

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APPENDIX A

LIGHTWEIGHT AGGREGATE KILN TESTS - 1977

APPENDIX A

LIGHTWEIGHT AGGREGATE KILN TESTS - 1977

INTRODUCTION

During preliminary discussions with the Lehigh Portland Cement Company in 1975-76, it was agreed that, as a prerequisite to burning RDF in their cement kilns in Union Bridge, Maryland, it would be necessary to first conduct preliminary tests in their lightweight aggregate (expanded shale) kiln in Woodsboro, Maryland. This kiln, although similar to a cement kiln, required less fuel per hour and produced a product that was not expected to be affected chemically by the use of RDF. The test would provide data on handling and burning RDF and provide experience to both the project and to the Lehigh Portland Cement Company in working with RDF prior to committing to a full-scale test at the cement plant.

This appendix briefly describes tests conducted February 1 through March 17, 1977, prior to the grant period for which the main body of this report was prepared.

EQUIPMENT

The Woodsboro LWA plant mines and crushes shale which is then expanded or "bloated" in one of two 48.8 m (160 ft) X 3 m (10 ft) diameter rotary kilns. The temperature in the firing zone of the kiln approaches 1100°C (2000°F). About two tons of coal per hour (12,000 Btu per lb) are required for each kiln when run at production capacity. The rate of coal feed is controlled with an optical pyrometer aimed into the kiln.

The configuration of the RDF feed system for these tests (Figure A-1) was different from that for the later grant-supported tests in that the RDF

REMOTE PROCESSING FACILITY

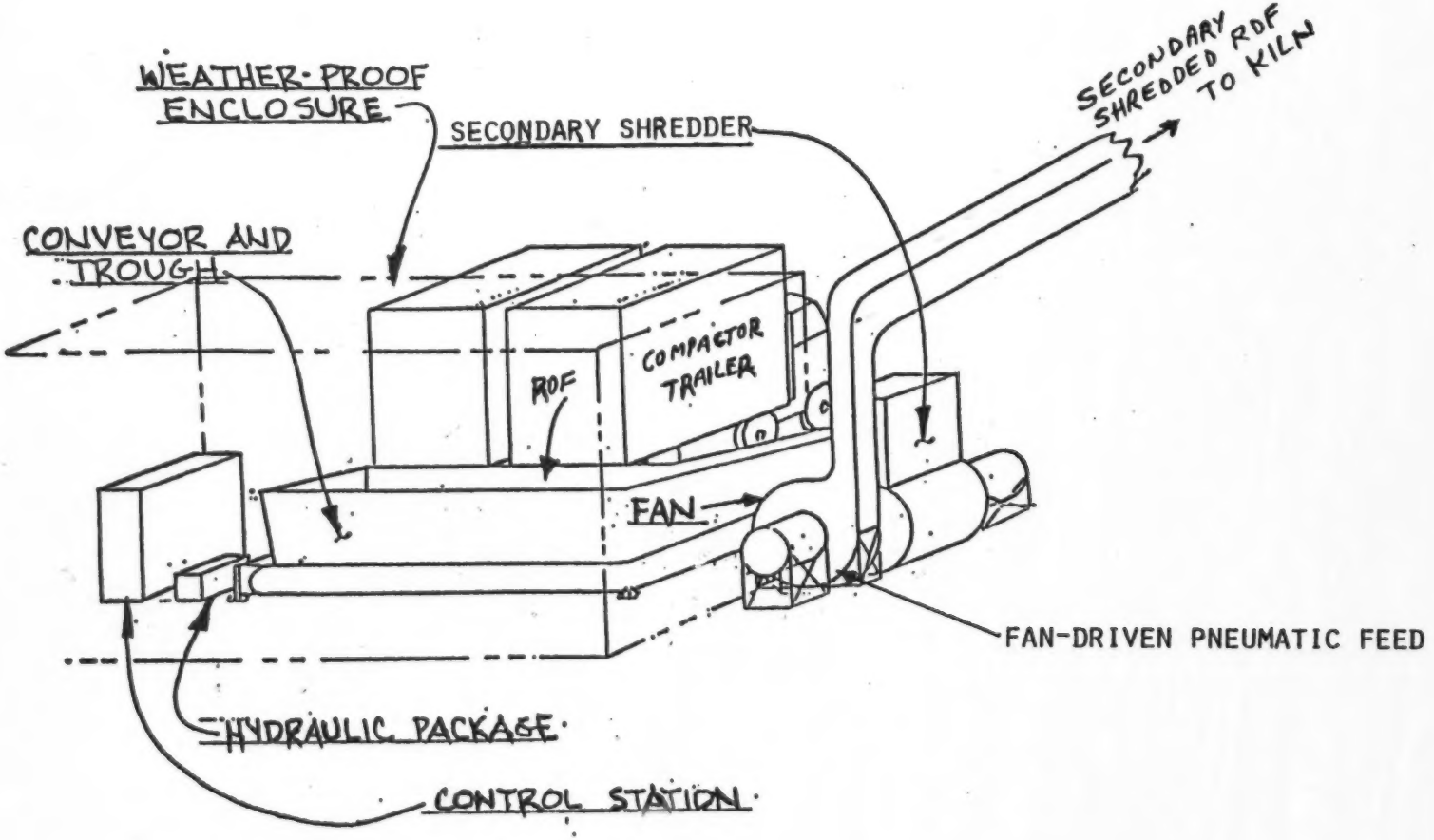

FIGURE A-1

was secondary shredded at the test site and blown into the kiln pneumatically with a fan rather than a positive displacement pump and air lock feeder. Also, the transfer trailer off-loading system used only one conveyor. The shredder was a Grundler Model 56-40, powered with a 350-hp motor. To inject RDF into the kiln, a 23 cm (9 in.) burner pipe was installed just to the right and at the same elevation as the kiln's coal burner pipe.

RDF TESTING

RDF testing commenced February 1, 1977 using a 3.8-cm (1.5-in.) grate (hole size) in the Grundler shredder. After an initial test of three hours, burning RDF at an average rate of one ton per hour, and two additional tests on succeeding days which followed adjustments to the kiln, it was apparent that RDF produced with this size grate would not burn satisfactorily in the kiln. Reasons for this conclusion were: (1) RDF burned on the shale bed, distorting pyrometer readings controlling the coal feed system; (2) RDF was burning beyond the normal flame zone, causing premature softening of the shale and the formation of "rings" (build-up) on the kiln wall; and (3) a product was being produced of greater density than normal production material.

As a result of these problems, a decision was made to switch to 1.3-cm (1/2-in.) grates in the shredder so as to produce smaller RDF particles. This modification plus an adjustment of the RDF burner position produced an unacceptable flame pattern in the kiln. However, ring formation, although under much better control, was still a problem. During the remainder of the month of February, additional, short tests were run while systematically adjusting instrument settings including kiln draft, hood draft, coal primary air, cooler compartment pressure, kiln speed and kiln discharge-end temperatures. Although minor adjustments were made to kiln draft and cooler compartment pressure, it was found that a 10 percent reduction in primary air to reduce the burning zone length had the most effect and made ring formation controllable. Nine tests were run using 67 tons of RDF fluff during this period; the longest continuous test was seven and one-half hours.

Starting on March 1, 1977, an attempt was made to conduct a continuous ten-day test. At the beginning of the test, modifications to the kiln operation were made in accordance with information collected during the February tests. When this was done, the kiln operation with RDF became stable and the operation routine. It was found that coal varied satisfactorily to automatically offset RDF flow changes and weights of the product were within tolerance and remained satisfactory throughout the ten-day test. RDF was igniting in the burning zone and maintaining approximately the same length of the normal burn zone. Instrument settings appeared to be satisfactory and ring formation was under control. The test, however, was interrupted several times due to problems in the RDF handling and shredding equipment. The interruptions included choking of the shredder, fires generated from operating the shredder in a choked condition, and severe wear of the hammers and grates in the shredder. The March tests burned 150 tons of fluff RDF.

CONCLUSIONS

The conclusions of these tests were that

(1) Fluff RDF could be satisfactorily burned as a supplemental fuel with coal, substituting for at least 30-40% of the heat, with no detrimental effect; in a kiln producing lightweight aggregate;

(2) Secondary shredding on site with a fan-driven pneumatic feed presented many operating and maintenance problems and was not an acceptable RDF feed arrangement.

FOLLOW-UP NOTE

As a result of these tests, the RDF feed system was modified as indicated in Section 5 of the main text.